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VARIATION OF GEOSTROPHIC WIND WITH POTENTIAL TEMPERATURE IN THE HORIZONTAL AND IN THE VERTICAL, WITH APPLICATION TO VERTICAL CROSS-SECTION DIAGRAMS

By A. G. MATTHEWMAN, B.A.

Vertical cross-section diagrams of the atmosphere which display the isopleths of geostrophic-wind component perpendicular to the cross-sections are of considerable interest, particularly in studies of the jet stream (*e.g.* Palmén[1]*, Nagler[2], Hovmöller[3], Durst and Davis[4], Nyberg[5]).

The computations on which the construction of the isopleths are based, can become excessively laborious. The purpose of the present article is to derive a convenient graphical means of constructing and checking these isopleths. The same problem has been considered on somewhat different lines by Bleeker[6]. The merits of the present treatment are that it applies to Form 2815†, it is reasonably quick and accurate, and certain reciprocal relations, which will be derived in this note, regarding the variation of geostrophic wind with potential temperature in the horizontal and in the vertical, are mutually helpful in constructing the detail in the neighbourhood of jet streams and of the tropopause.

Theory of the method.—The method is based on the geostrophic thermal-wind relation applied to dry-bulb (or more exactly, virtual) potential temperature. With the usual notation, the dry-bulb potential temperature θ is defined by

$$\theta = T\left(\frac{p_0}{p}\right)^{\frac{(\gamma-1}{\gamma}}$$

and the virtual potential temperature θ' by

$$\theta' = T'\left(\frac{p_0}{p}\right)^{\frac{(\gamma-1)}{\gamma}} \qquad \ldots \quad (1)$$

where T' is the virtual temperature, p_0 is some standard pressure, here taken, as usual, 1000 mb. and $\gamma = C_p/C_v$.

Take the horizontal direction from left to right in the plane of the vertical cross-section as the axis of x, and the vertical direction as the axis of z or p. The hydrostatic equation is

$$\left(\frac{\partial z}{\partial p}\right)_x = -\frac{1}{g\rho}$$

Substituting for ρ from the equation of state $p = R\rho T'$,

$$\left(\frac{\partial z}{\partial p}\right)_x = -\frac{RT'}{gp},$$

*The index numbers refer to the list of references on p. 102.

†Meteorological Office, London, Form 2815. Vertical cross section of the atmosphere (large scale).

and for T' in this last equation from equation (1)

$$\left(\frac{\partial z}{\partial p}\right)_x = -\frac{R}{g}\cdot\theta'\cdot\frac{p^{-1/\gamma}}{p_0^{(1-1/\gamma)}} \quad \text{.. (2)}$$

The geostrophic component v_J directed perpendicular to, and to the left of the axis of x is given by

$$v_J = \frac{g}{\lambda}\left(\frac{\partial z}{\partial x}\right)_p \quad \text{.. (3)}$$

By (3),

$$\left(\frac{\partial v_J}{\partial p}\right)_x = \left[\frac{g}{\lambda}\cdot\frac{\partial}{\partial p}\cdot\left(\frac{\partial z}{\partial x}\right)_p\right]_x$$

$$= \frac{g}{\lambda}\left[\frac{\partial}{\partial x}\cdot\left(\frac{\partial z}{\partial p}\right)_x\right]_p$$

which by (2)

$$= \frac{g}{\lambda}\left[-\frac{R}{g}\cdot\frac{p^{-1/\gamma}}{p_0^{(1-1/\gamma)}}\left(\frac{\partial\theta'}{\partial x}\right)_p\right]$$

Thus

$$\left(\frac{\partial v_J}{\partial p}\right)_x = -\frac{R}{\lambda}\cdot\frac{p^{-1/\gamma}}{p_0^{(1-1/\gamma)}}\left(\frac{\partial\theta'}{\partial x}\right)_p \quad \text{.. (4)}$$

Now

$$\left(\frac{\partial v_J}{\partial\theta'}\right)_x = \frac{\left(\frac{\partial v_J}{\partial p}\right)_x}{\left(\frac{\partial\theta'}{\partial p}\right)_x}.$$

Hence by (4),

$$\left(\frac{\partial v_J}{\partial\theta'}\right)_x = -\frac{R}{\lambda}\cdot\frac{p^{-1/\gamma}}{p_0^{(1-1/\gamma)}}\frac{\left(\frac{\partial\theta'}{\partial x}\right)_p}{\left(\frac{\partial\theta'}{\partial p}\right)_x}$$

$$= +\frac{R}{\lambda}\cdot\frac{p^{-1/\gamma}}{p_0^{(1-1/\gamma)}}\left(\frac{\partial p}{\partial x}\right)_{\theta'}$$

$$= \frac{1}{\lambda}\cdot\frac{R}{(1-\frac{1}{\gamma})}\cdot\frac{1}{p_0^{(1-1/\gamma)}}\left\{\frac{\partial}{\partial x}\left(p^{1-1/\gamma}\right)\right\}_{\theta'} \quad \text{.. (5)}$$

Now define Z such that

$$-aZ + b = p^{(1-1/\gamma)}$$

where a, b are constants, a positive, and write

$$k = a\,\frac{R}{(1-\frac{1}{\gamma})}\cdot\frac{1}{p_0^{(1-1/\gamma)}}$$

another constant, also positive.

Then (5) may be written

$$\left(\frac{\partial v_J}{\partial\theta'}\right)_x = -\frac{k}{\lambda}\left(\frac{\partial Z}{\partial x}\right)_{\theta'} \quad \text{.. (6)}$$

Now

$$\left(\frac{\partial v_J}{\partial\theta'}\right)_p\cdot\left(\frac{\partial\theta'}{\partial x}\right)_p = \left(\frac{\partial v_J}{\partial x}\right)_p$$

and

$$\left(\frac{\partial v_J}{\partial\theta'}\right)_x\cdot\left(\frac{\partial\theta'}{\partial p}\right)_x = \left(\frac{\partial v_J}{\partial p}\right)_x$$

Hence

$$\frac{\left(\frac{\partial v_J}{\partial \theta'}\right)_p}{\left(\frac{\partial v_J}{\partial \theta'}\right)_x} = \frac{\left(\frac{\partial v_J}{\partial x}\right)_p}{\left(\frac{\partial v_J}{\partial x}\right)_x} \Bigg/ \frac{\left(\frac{\partial \theta'}{\partial x}\right)_p}{\left(\frac{\partial \theta'}{\partial p}\right)_x}$$

$$= \frac{\left(\frac{\partial p}{\partial x}\right)_{v_j}}{\left(\frac{\partial p}{\partial x}\right)_{\theta'}}$$

which, from the definition of $\mathcal{Z}$ above,

$$= \frac{\left(\frac{\partial \mathcal{Z}}{\partial x}\right)_{v_j}}{\left(\frac{\partial z}{\partial x}\right)_{\theta'}} \qquad .. \quad (7)$$

From (6) and (7) it follows that

$$\left(\frac{\partial v_J}{\partial \theta'}\right)_p = -\frac{k}{\lambda}\left(\frac{\partial \mathcal{Z}}{\partial x}\right)_{v_j} \qquad .. \quad (8)$$

The reciprocal relations.—Equations (6) and (8) state that, on a vertical cross-section diagram with suitable ordinate $\mathcal{Z}$, in a given latitude, the rate of change of v_J (the geostrophic component perpendicular to the cross-section) with virtual potential temperature θ' (i) along the vertical is proportional to the slope of the isopleths of θ' and (ii) along the horizontal is proportional to the slope of the isopleths of v_J. Moreover, the factors of proportionality in (i) and (ii) are the same. It is these relations which form the basis of the graphical method here proposed.

Vertical cross-section diagrams could be prepared, with ordinate $\mathcal{Z}$ as defined, for the direct application of these relations. However, the diagram generally used in the British meteorological service (Form 2815) is one in which the linear ordinate is the I.C.A.N. height. Since the I.C.A.N.-height scale is very nearly a linear function of $\mathcal{Z}$, the reciprocal relations can be applied without difficulty to Form 2815.

A scale has therefore been prepared, which by measuring the slopes of the isopleths of θ' and v_J gives directly the change in v_J, in knots per 10°F. of potential temperature, in the horizontal and vertical directions. This scale will now be described.

Vertical cross-section scale.—The scale, which is transparent, fits over Form 2815 (see Fig. 1 (*a*)). The scale of the abscissa of the cross-section is taken to correspond to a conical-orthomorphic projection, scale $1 : 7{\cdot}5 \times 10^6$, standard parallels 30° and 60°.

The 1013-mb. line (I.C.A.N.-height zero) on the scale coincides with the corresponding line marked on Form 2815.

The scale is marked with a vertical line on the left and a series of vertical lines each for the appropriate latitude (30° to 70°) on the right.

These vertical lines carry unit markings of $\mathcal{Z}'$ from -3 to $+83$, their relation to the I.C.A.N.-height scale of h, say, in kilometres, being given in the following table:—

TABLE I

Z'	0	5	10	15	20	25	30	35	40
					kilometres				
I.C.A.N. height	0	0·75	1·49	2·25	3·00	3·77	4·55	5·33	6·13

Z'	45	50	55	60	65	70	75	80
				kilometres				
I.C.A.N. height	6·92	7·73	8·54	9·38	10·21	11·04	11·92	12·83

On the scale, the distance *d* say, in centimetres between the left-hand vertical line and the vertical line corresponding to various latitudes from 30° to 70° is given in the following table.

TABLE II

			degrees		
Latitude ϕ	30	40	50	60	70
			centimetres		
Distance *d*	9·95	7·51	6·28	5·74	5·73

For a horizontal scale of 1 : 15 × 10^6, values of *d* are divided by 2. A copy of the cross-section is shown in Fig. 1.

Use of the scale.—On the cross-section Form 2815, the isopleths of potential temperature are drawn at 5°F. or 10°F. intervals.

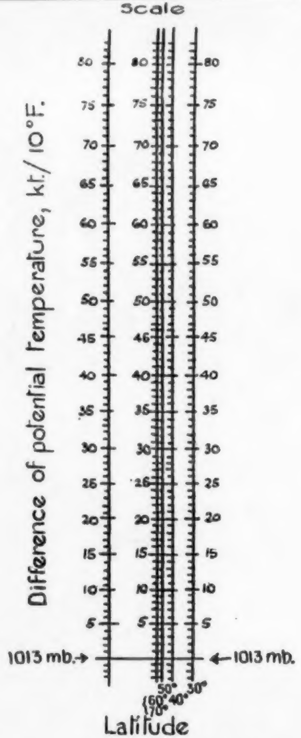
The values of v_J, the geostrophic wind component at right angles to the cross-section (directed into the paper) at some low level, *e.g.* 1000 mb., measured on the appropriate synoptic chart at sufficient points, are entered along the line of the cross-section. Then the scale is placed over the cross-section, with the 1013-mb. lines coinciding. A ruler or straight edge is placed tangential to the isopleths of potential temperature at any point of the scale, and where the ruler crosses the vertical lines of the scale the value in units on the vertical line on the left is subtracted from the value on the vertical line on the right for the appropriate latitude. This subtraction gives the decrease in knots of the geostrophic component v_J along the vertical per 10°F. increase in potential temperature.

Starting from a known value of v_J (say at 1000 mb.) the values of v_J in a series of steps of 10°F. potential temperature along any vertical of the cross-section can thus be obtained, and a set of isopleths of v_J sketched in.

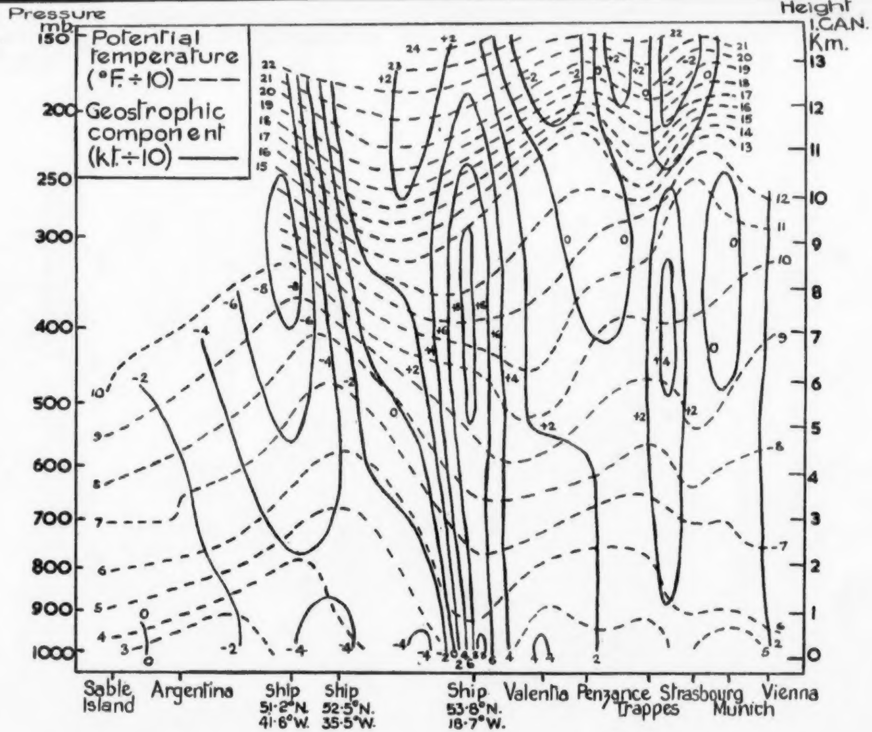
The same scale can now be applied to these provisional isopleths of v_J. Where a ruler placed across the scale tangential to an isopleth of v_J crosses the vertical lines of the scale, the value in units on the vertical line on the left is subtracted from the value on the vertical line on the right for the appropriate latitude. This subtraction gives the decrease in knots of the geostrophic component v_J along the horizontal per 10°F. increase in potential temperature. If necessary the isopleths of v_J can be adjusted until consistency is obtained.

Example.—Fig. 1 (*b*) shows a vertical cross-section from Sable Island to Vienna on March 31, 1948, at 0300 G.M.T. A wave depression at that time was centred (at mean sea level) about 70 miles north-west of the ship at 53·8°N. 18·7°W. with central pressure about 965 mb., and was deepening and moving east by north.

On the cross-section, isopleths of dry-bulb potential temperature have been drawn from the reported values, at intervals of 10°F.



(*a*) Vertical cross-section scale



(*b*) Vertical cross-section 0300 G.M.T., March 31, 1948

FIG. 1

Isopleths of v_J, the geostrophic wind component perpendicular to the cross-section (directed into the paper) are drawn at intervals of 20 kt. from (i) the values of v_J at mean sea level at points along the cross-section, and (ii) the variation of v_J with steps of 10°F. potential temperature along the vertical and horizontal axes by use of the scale described above (with horizontal scale here $1 : 15 \times 10^6$).

The author is indebted to Dr. Sutcliffe for criticisms and to Mr. Sawyer for the checking of the computations involved in constructing the scale.

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METHOD FOR FORECASTING THE TIME OF CLEARANCE OF RADIATION FOG OR LOW STRATUS

By G. J. JEFFERSON, M.Sc.

Assuming that the temperature required to clear fog or low stratus can be estimated by methods already evolved, a graphical method is devised of deciding when the required temperature will be reached on mornings when no cloud impedes the solar-radiation beam. Time-temperature curves are forecast and drawn for each occasion starting from the forecast clear-morning curve between sunrise and the time of diurnal maximum temperature which is modified according to the expected delay factor due to absorption and reflection of the solar radiation by the fog or stratus layer.

To forecast the time of clearance of fog or low stratus it is the normal practice for an estimate to be made of a screen temperature which is sufficient to clear the fog or cloud on the assumption of a convective layer with approximately a dry-adiabatic lapse rate. With this temperature estimated it is necessary to decide if and when it will be reached taking account of the season of the year, the density of the fog or cloud, and any screening by higher layers of cloud.

In another paper[1]* Gold's method[2] of forecasting maximum day temperatures was empirically extended for Northolt to give an estimated curve of temperature rise with time after sunrise in cases of clear sky. This curve is shown by the continuous line in Fig. 1.

The basic idea of the earlier article is that the heat energy absorbed by the surface layers of the atmosphere up to a certain time after dawn will be roughly constant at a given season of the year and will be represented by a constant area on the tephigram.

When the incoming solar radiation is interrupted by fog or cloud the rate of heating is reduced, and it was thought that, by introducing a form of "delay

*The index numbers refer to the list of references on p. 109.

factor " representing the reduction in the rate of heating and estimated from the thickness of the fog or cloud, it might be possible to estimate an adjusted heating curve taking a clear-sky curve for the season as a basis.

Let us assume that up to any given time after sunrise the amount of heat added to the lowest layers of air is, with fog conditions, 50 per cent. of what it would have been with a clear sky. Assuming the delay factor to be constant during the heating period it will take twice as long from sunrise for a given temperature rise to take place as on a clear day.

We can then draw a corrected forecast-temperature curve shown by the broken line on Fig. 1. This can be drawn making BC = AB for any given temperature. When the temperature reaches T_c, the temperature required to clear the fog, the time of clearance is read from the abscissa at H. After T_c has been passed the curve rises more steeply and more in line with clear-day characteristics, although if the clearance is late the maximum temperature reached is likely to be below what it would have been had there been no fog or stratus. If T_c has not been reached by the time of maximum temperature, M, then one would forecast no clearance of the fog or stratus.

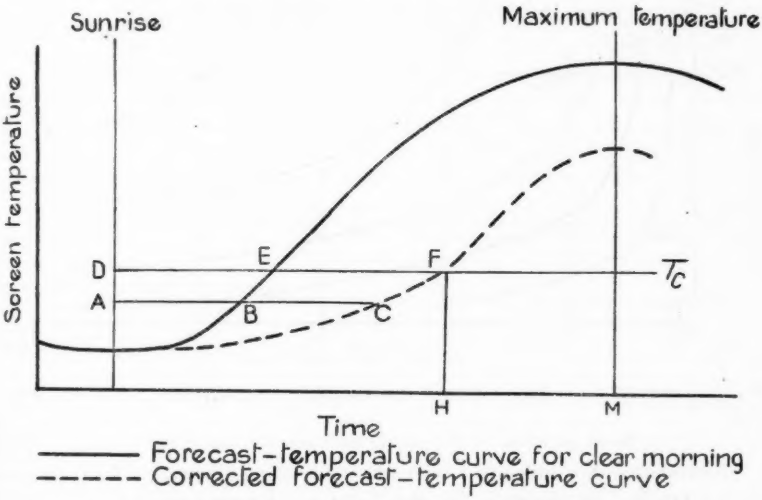

FIG. 1—CORRECTED FORECAST-TEMPERATURE CURVE

Tc is the temperature required to clear fog or low stratus by morning solar radiation

In the same way a corrected curve can be drawn for any other delay factor making AB/AC equal to the delay factor at every temperature below T_c.

In practice this can be done conveniently by putting a graduated scale along the line ABC and marking a number of points C which are afterwards joined by a smooth curve. If T_c is not reached by time M then the maximum temperature to be expected can be forecast.

The theory of the problem is very complicated, but an order of magnitude may be obtained by assuming that the rate of heating of the surface layers (as represented by area on the tephigram) is reduced in proportion to the short-wave solar radiation which penetrates the fog or cloud. The use of this in practice demands a transmission factor for use on each separate occasion.

To derive some idea of what it would be, use has first been made of figures given by Hewson[3] who provided transmission values for fog, assuming a droplet radius of 2×10^{-3} cm., and cloud, assuming a droplet radius of 5×10^{-4} cm. These figures are given for three values of the sun's zenith distance. Since the period for which the value is most important is from sunrise to about midday, the values for 78·7° were used.

Hewson's values were plotted on a graph of thickness, in metres, against density of water, in grams per cubic metre, and curves of equal transmission percentage drawn as shown in Fig. 2. Some estimate of the water content can be made, especially in the case of fog, from the humidity mixing ratio, sunrise temperature and probable midday dew point of the air. The depth of fog, however, is difficult to estimate with any accuracy, although a rough idea can be formed by the amount of light transmitted and the time when the fog formed. Any observations by aircraft can, of course, be used with advantage. It is apparent that for practical forecasting the number of variables, whose values can at best be only estimated, is too great for the transmission value to be accurately decided without more data than is available in a normal forecasting office.

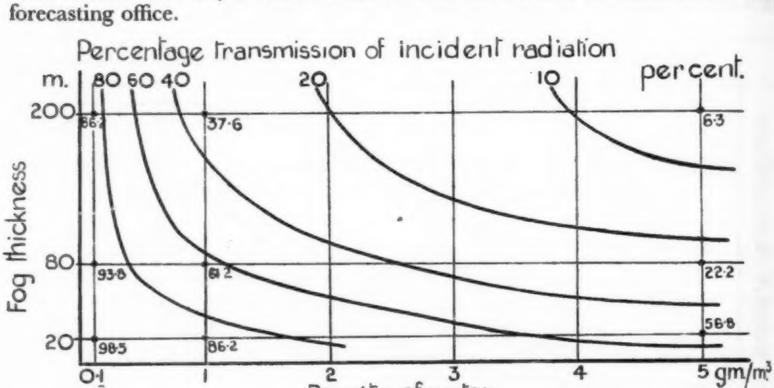

FIG. 2—PERCENTAGE TRANSMISSION OF INCIDENT RADIATION THROUGH LAYERS OF FOG

Based on values by Hewson for sun's zenith distance 78·7°

To overcome this difficulty a start was made using arbitrary values. Hewson gives 1 gm./m.³ for moderate fog and 5 gm./m.³ for very dense fog. Values of 1·5–2 gm./m.³ which appeared to be a possible value for thick morning fog and thickness of 100–150 m. (300–500 ft.) were used. These figures give transmission values of the order of 30–50 per cent. which give the sort of curve which would be expected although similar percentages of transmission can be obtained from Hewson's figures by taking 0·8–1·5 gm./m.³ water content and a thickness of 150–200 m. (500–600 ft.).

Using this as a basis, forecast curves were drawn on a number of mornings when it was known that there was clear sky above the layer of radiation fog. Transmission values of 30 per cent. were used when the fog was dense and of some hours' duration, but nearer 50 per cent. when it was thin and of recent formation. The actual temperatures which were observed are also plotted on the examples included with this article which are all copied from diagrams used to make actual forecasts.

It can be seen that generally speaking the curves of actual temperatures do appear to justify the percentages chosen. In some cases it was found possible to issue an amended forecast of the expected clearance time when the rate of rise of temperature in the first few hourly periods after sunrise enabled a revised delay factor to be estimated.

Such a case occurred on March 4, 1948, at Gatow, as shown on the accompanying example, Fig. 4, where an original forecast of clearance at 0930 G.M.T. based on a delay factor of 40 per cent. was amended to 25 per cent., in this way giving a clearance about 1200 G.M.T. which it will be seen was much nearer the truth as no real clearance actually occurred all day. On October 5, 1947, in the curves for Northolt, an original forecast of 0930 G.M.T. based on 50 per cent. delay factor is shown, while the curve of actual temperature gave 40 per cent. and a clearance time about one hour later.

Of the nine examples given seven are in the months of March and October, and there is reason to think that the spring and autumn seasons are the times of year when the method is likely to prove most useful and effective. In the summer months morning fog is rare, while in the winter months the amount of heat energy absorbed from insolation by the surface layers and accompanying rise of temperature are small, and when reduced further by a fog layer will tend to be masked by other local variations. This can be seen from the other two examples given, particularly from that of November 29, 1948, when temperature fell steadily throughout the heating period due to the slow but steady advection of colder air. Furthermore, it is on mornings in spring and autumn, when the fog clearance may be expected to be fairly sudden, that an accurate forecast of clearance time is of most value for aviation.

The remaining seven examples have been analysed and the results shown in the accompanying table. The delay factor, which the actual temperature curve shows as compared with the forecast clear-morning curve, has been computed for periods of two to six hours from sunrise.

Place	Date	2*				3*				4*			
		Delay factor	Visibility	Cloud Amount	Cloud Height	Delay factor	Visibility	Cloud Amount	Cloud Height	Delay factor	Visibility	Cloud Amount	Cloud Height
		%	yd.	tenths	ft.	%	yd.	tenths	ft.	%	yd.	tenths	ft.
Northolt	5.10.47	26	100	sky obscured		36	200	sky obscured		37	60	sky obscured	
Gatow	13.10.47	..	..	..	..	..	..	..	..	..	..	..	..
Northolt	21.10.47	..	..	..	..	..	..	..	..	35	300	0	0
Gatow	6.12.47	..	..	..	..	..	..	..	..	52	600	10	200
Gatow	3. 3.48	46	200	0	0	37	200	0	0	34	700	0	0
Gatow	4. 3.48	20	100	sky obscured		22	200	sky obscured		26	400	0	0
Gatow	5. 3.48	44	100	0	0	34	200	0	0	30	700	0	0
Gatow	7. 3.48	40	100	0	0	34	700	0	0	34	900	0	0

Place	Date	5*				6*			
		Delay factor	Visibility	Cloud Amount	Cloud Height	la Dey factor	Visibility	Cloud Amount	Cloud Height
		%	yd.	tenths	ft.	%	yd.	tenths	ft.
Northolt	5.10.47	49	60	0	0	..	..	..	..
Gatow	13.10.47	41	800	10	600	45	3,500	10	600
Northolt	21.10.47	..	..	..	..	..	..	..	..
Gatow	6.12.47	49	900	10	200	42	400	sky obscured	
Gatow	3. 3.48	38	1,200	0	0	..	..	..	..
Gatow	4. 3.48	24	900	0	0	22	600	0	0
Gatow	5. 3.48	32	800	0	0	34	700	0	0
Gatow	7. 3.48	..	..	..	..	..	..	..	..

*Hours from sunrise.

The results suggest that in most cases of morning fog in spring and autumn a factor of about 35 per cent. is correct for the periods from sunrise to beyond three hours until the clearance time approaches. The temperature rise expected

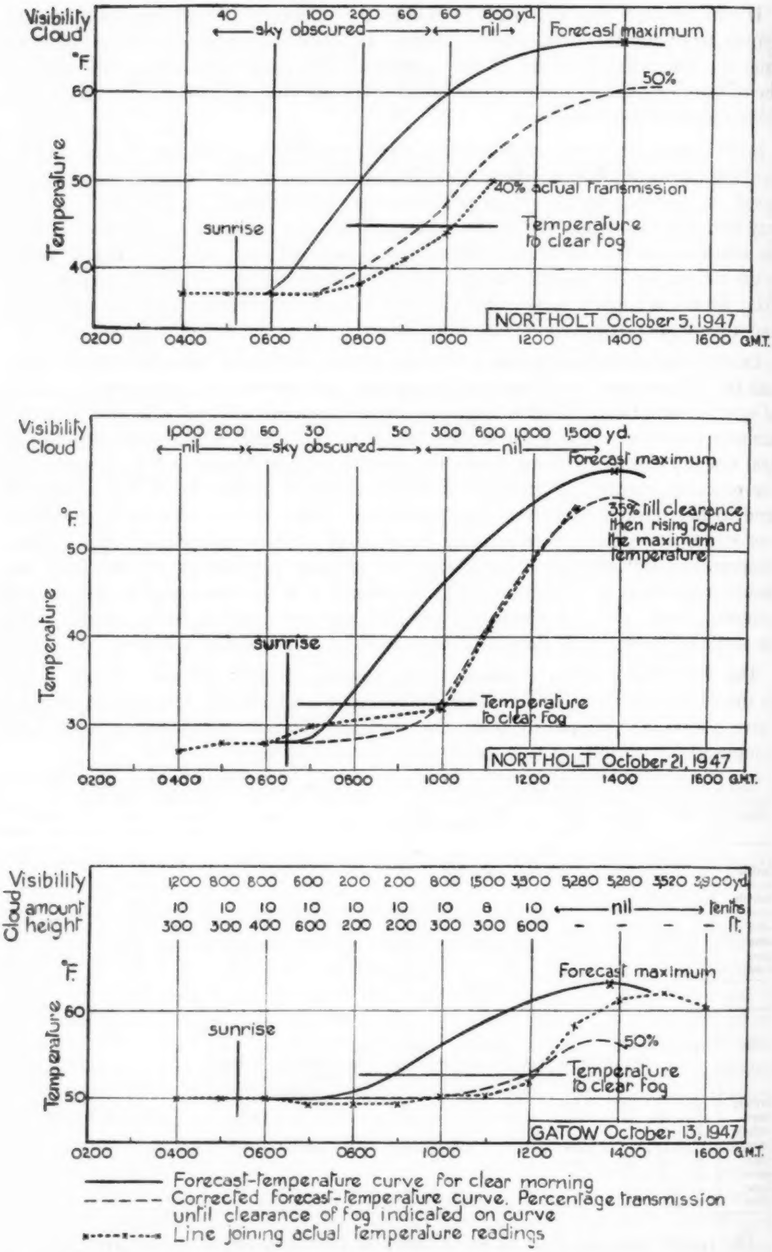

FIG. 3—EXAMPLES OF CORRECTED FORECAST-TEMPERATURE CURVES

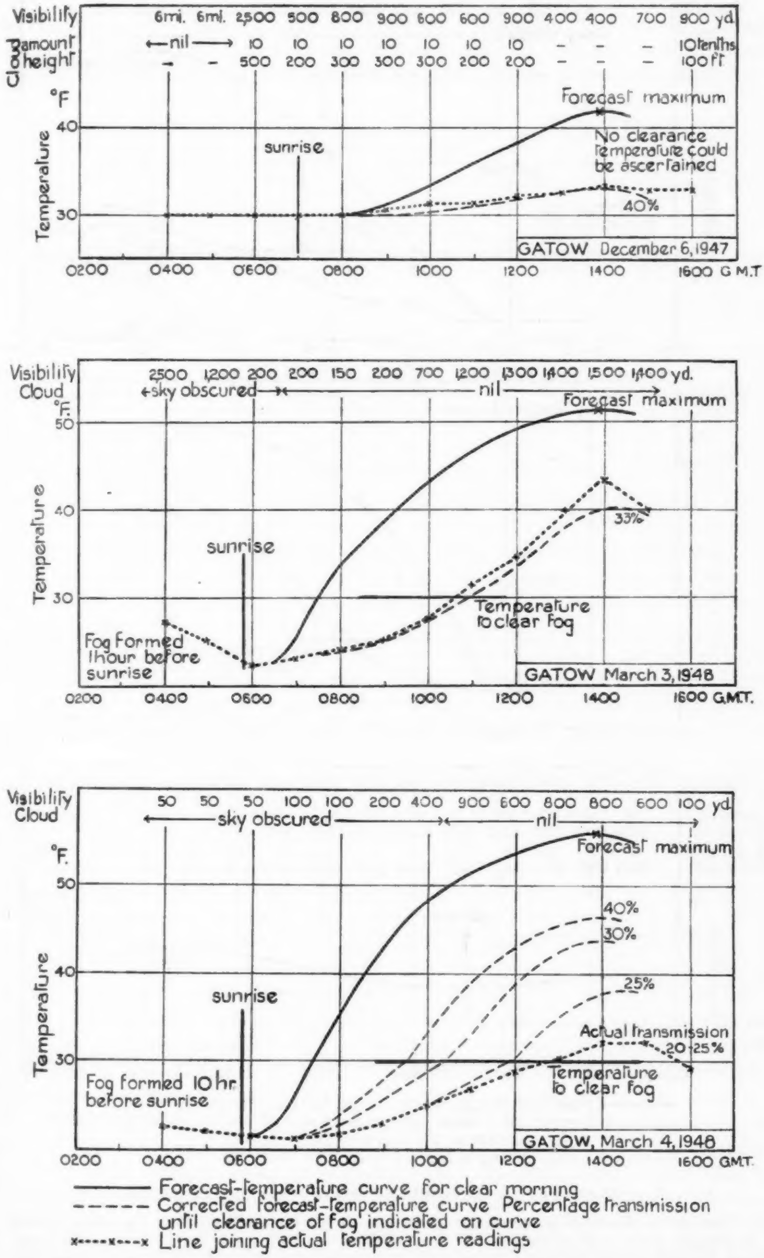

FIG. 4—EXAMPLES OF CORRECTED FORECAST-TEMPERATURE CURVES

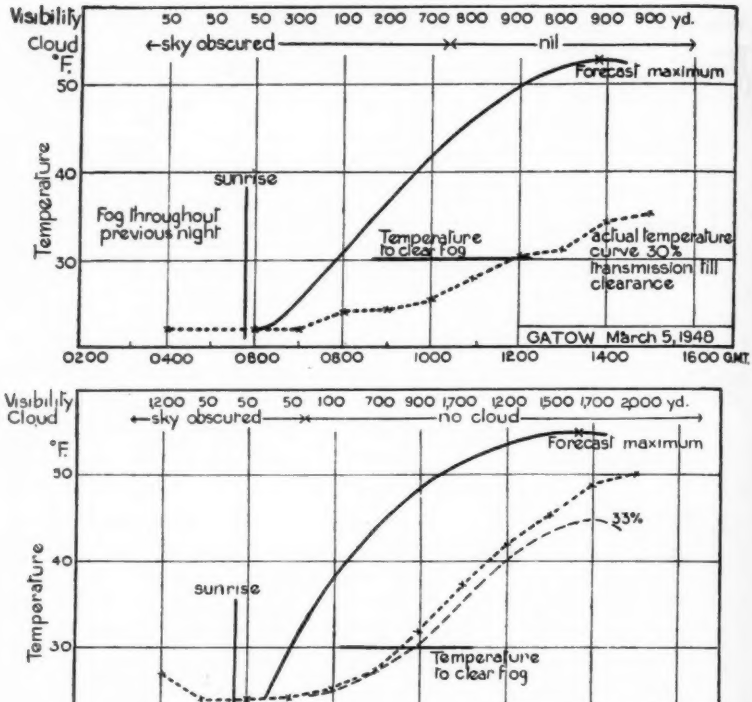

FIG. 5.—EXAMPLES OF CORRECTED FORECAST-TEMPERATURE CURVES

The curve of actual temperature recordings at Gatow on November 29, 1948, appears to suggest there was advection of colder surface air during the day. A steep inversion was present above the cloud layer with a temperature of 40°F. from 950 to 850 mb. An aircraft report gave the top of the cloud layer as 1,300 ft. between 1400 and 1500 G.M.T.

in a period shorter than three hours is too small for any accurate factor to be ascertained. On occasions of thicker fog as exemplified on March 4, 1948, when the fog formed some ten hours before sunrise 25 per cent. would appear a better figure. A rough classification can thus be made for typical morning fogs in autumn and spring:—

(*a*) thin and shallow, delay factor 35 per cent.

(*b*) thick and deep, delay factor 25 per cent.

I wish to acknowledge advice given by Dr. Sutcliffe in the preparation of this and the earlier[1] article.

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RADAR WEATHER ECHOES

By R. F. JONES, B.A.

Part I

The fact that radar echoes are received from certain types of weather phenomena, when the radar wave-length is sufficiently small, is now well known, and most readers will be familiar with the photographs of such echoes which have appeared from time to time in various publications. The most usual type of presentation used in these photographs has been that provided by the Plan Position Indicator or P.P.I., which gives the projection of the radar echoes received from the surrounding atmosphere on the (almost) horizontal plane through the radar set. The area covered extends usually to a radius of about 60 miles from the radar set although, exceptionally, greater ranges have been displayed. Less frequently, various types of presentation have been used which show a cross-section of a particular echo in the vertical plane along a certain bearing from the radar set. The wave-length used in all cases has been either 10 cm. or 3 cm.

It has been well established that the weather echo is caused by the back-scattering of the radio energy from the solid and liquid particles in the atmosphere, *e.g.* ice crystals, snow-flakes, cloud droplets and raindrops. In the case of spherical liquid drops it has been shown theoretically[1*], and borne out by experiment, that the amount of energy back-scattered to the radar receiver is proportional to the expression ΣND^6, where N is the number of drops of diameter D per unit volume. For solid particles the echo intensity depends primarily on the mass of the ice crystal or snow-flake and the precipitation rate[1].

Clearly for any radar receiver there is a minimum receivable power which can be detected and there is, therefore, for rainfall a value of the expression ΣND^6 below which no echo will be detected, this minimum value depending on the efficiency of the receiver and the wave-length employed. For most, if not all, of the 10-cm. sets used, and probably for the 3-cm. sets also, it is highly probable that this minimum value of ΣND^6 is such that, at ranges greater than 10 miles, the echo comes from water-drops of raindrop size, *i.e.* the echo received is from precipitation although this precipitation may not always reach the ground, *e.g.* in strong vertical currents it is possible that drops of raindrop size may be suspended or moving upwards in the vertical current, or on another occasion with high-level precipitation the drops may evaporate before reaching the ground. In the case of snow there will likewise be a minimum size of snow

*The index numbers refer to the list of references on p. 112.

crystal or snow-flake or minimum value of precipitation rate below which no radar echo will be received. At the moment of melting of the ice crystal the position is more complex, but it has been shown[1] that an enhancement of the echo is likely to occur at this time and the occurrence of a "bright band" of echo close to the freezing level in conditions of weak vertical currents has frequently been observed.

For the full theory of radar echoes from precipitation the reader is referred to a paper by Ryde[1] while the interpretation of various types of weather echo on the basis of this theory has been discussed in a report to the Meteorological Research Committee by the writer[2].

For our purposes it can be accepted that in a particular weather situation the radar echoes seen do not come from the whole volume of the clouds present but only from those parts of the clouds, and the volume beneath them, which contain (i) raindrops of a sufficient size and concentration, or (ii) individual ice crystals of a sufficient size and concentration, or (iii) snow-flakes formed from an aggregate of ice crystals of a sufficient concentration.

For rather more than two years weather echoes have been observed and photographed, using radar sets having a wave-length of 10 cm., at the Meteorological Office radar station at East Hill (near Dunstable). The photographs are principally from two different types of presentation, the P.P.I. presentation mentioned above and the Height-Range Tube (H.R.T.) presentation which gives the range and height of the observed echo directly and hence the vertical section through a weather echo when observed on a fixed bearing. There is now a large collection of photographs of weather echoes on these two presentations covering almost every type of weather situation which affects the Midlands of England and which are probably typical of similar situations elsewhere in the temperate zone. In the following sections are given examples of the radar echoes in the horizontal and vertical sections in various types of weather situation.

Cold front by radar.—The typical P.P.I. picture of a cold front (see photograph (*a*) of series of photographs between p. 112 and p. 113) shows it as a long and generally very narrow band of echo stretching across the face of the display tube and visible on occasions to ranges greater than 40 miles. The band of echo is rarely quite continuous, although the cloud associated with the front is almost certainly so, but is formed of a large number of small cores of echo of quite high intensity very close together and even at short ranges the cellular structure remains.

When seen in the vertical cross-section (photographs (*b*) and (*c*)) the cellular structure is again demonstrated, the cores of high intensity being associated with strong vertical columns of echo. The probability is that these cores are associated with relatively strong vertical currents, compared with those existing in the remainder of the frontal cloud, and marked turbulence, and probably come from cumulonimbus clouds embedded in the frontal-cloud system, while the spaces between them which are clear of echo are probably areas of down currents.

The whole frontal-cloud system does not contain radar-reflecting particles of sufficient size and concentration to give a radar echo with our equipment, and the responses obtained show that on a large number of occasions the moderate to heavy rain of the front must be confined to a very narrow belt, only a few miles wide, at the leading edge of the front.

Exceptionally, the precipitation area associated with the front, as shown by the radar, may be much wider than usual (photograph (*d*)) but even on these occasions the heaviest precipitation and probably the strongest vertical currents and turbulence are confined to a narrow belt as shown by the vertical cross-section on the radar in such cases (photographs (*e*) and (*f*)). In these cases behind the strong vertical columns at the leading edge of the front the vertical cross-section shows a mass of echo with a level and diffuse top. This echo is almost certainly from large ice crystals or snow-flakes in the altostratus sheet behind the surface position of the front, and the level and diffuse top is interpreted as evidence of widespread but weak upward currents and little turbulence.

The picture of the cold front as interpreted from the radar evidence is thus in keeping with the generally accepted idea of the cold front (see, for example, "Meteorology for Aviators", p. 182[3]) with the exception that, in the Midlands of this country at least, the part of the cold front which has cumulonimbus characteristics is confined to a narrow belt of the order of 5–10 miles in width. Further details of the photographic illustrations are given below:—

Photograph (*a*). This P.P.I. photograph was taken at 1241 G.M.T. on November 12, 1947. The circular markers are at 5-mile intervals (the first complete circle visible being 10 miles from the station) while the radial lines are azimuth indicators at 20° intervals, the brightest one being at magnetic north. The echoes inside the 10-mile circle are permanent echoes from the high ground in the neighbourhood of the station and the short lines of echoes on about 270° and 290° from 10–15 miles are also permanent echoes. The belt of echoes associated with the cold front is some 85 miles long, but is nowhere wider than about 2–3 miles.

Photograph (*b*). This is an H.R.T. photograph taken at 1108 G.M.T. on August 25, 1948, on a bearing of 45° true, looking along a cold front at the moment when the front was passing over the station. Echoes from the front are visible to a range of about 35 miles in this direction and the tendency for the echo to divide into separate columns of echo is noticeable.

Photograph (*c*). This H.R.T. photograph was also taken on August 25, 1948, on a bearing of 307° true at 1029 G.M.T. as the cold front approached the station, and gives a section of the front approximately perpendicular to the line of the front and demonstrates the narrow width and column structure of the echo in this direction. The high-level response at 20,000 to 25,000 ft. is presumably from large ice crystals in the upper cloud of the front which decrease in size by evaporation in falling through a drier layer below 20,000 ft. with a consequent disappearance of the weather echo. The furthest echo at about 60 miles range is from a cumulonimbus which has developed in the cold air behind the front.

Photograph (*d*). This P.P.I. photograph was taken at 1051 G.M.T. on September 16, 1947. The range markers are not shown in their entirety but appear as spots at 5-mile intervals on the 20° azimuth indicators. The responses within 10 miles are (as in photograph (*a*)) from permanent echoes. The belt of echo nearest to the station is of greater intensity than the remainder, and, as shown in photograph (*e*), is probably associated with a narrow line of cumulonimbus clouds at the surface position of the front.

Photograph (*e*). This photograph, taken at 1044 G.M.T., shows the vertical section through the cold front of photograph (*d*) on a bearing of 255° magnetic. The cumulonimbus development in the front, as indicated by the tendency to column structure in the echo, is confined to a depth of less than 10 miles.

Photograph (*f*). This photograph was taken at 0738 G.M.T. on April 22, 1947, on a bearing of 69° true, some time after a cold front had passed through the station. The responses at 43–48 miles, although considerably attenuated due to the range at which they were viewed, show signs of column structure and were received from the surface position of the cold front. The remaining echo is associated with the altostratus sheet behind the front which was just clearing the station at the time of the photograph. There was no indication in the neighbourhood of the station of rain reaching the ground, and it is thought that the responses at ranges up to 15 miles at least were from large ice crystals or snow-flakes at 10,000–15,000 ft. which evaporated in the drier air beneath the frontal surface and completely vanished before reaching the ground, the ice crystals having already become too small to give a radar echo by the time they had fallen below 10,000 ft. Nearer to the surface cold front, with a decreasing cloud height and less depth of drier air, the height of the base of the radar echo also decreases.

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METEOROLOGICAL OFFICE DISCUSSION

The discussion on Monday, February 6, 1950, took the form of a symposium on the measurement of visibility. The opening speaker was Mr. G. J. W. Oddie.

Definitions and their consequences.—For meteorological purposes daylight visibility is defined as the distance at which dark objects, seen against the horizon sky as background, are just distinguishable for what they are. The objects selected should, if possible, subtend an angle of more than ½° in width and height (*i.e.* 46 ft. at one mile) and not more than 5° in width. Visibility at night is defined as the distance at which standard daylight objects would be just distinguishable if it were daylight and the atmospheric transparency were unchanged.

Daylight visibility observations are of direct use in many practical problems of seeing but night visibility observations require conversion, usually to the visual range of lights of specified candle power.

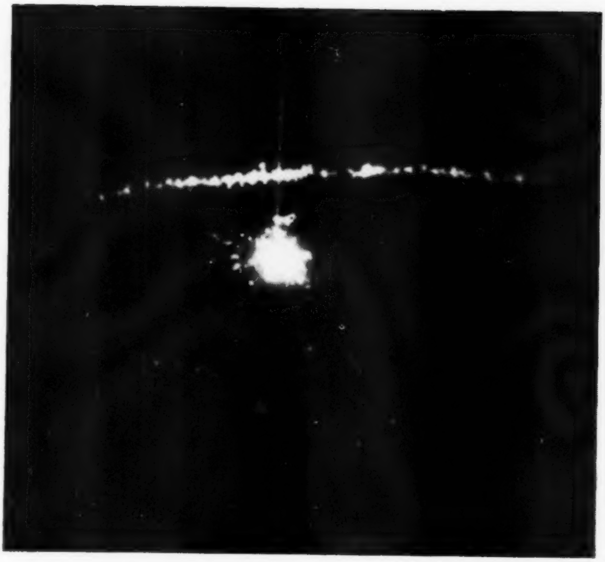
Since visibility as defined above is a subjective quantity, it cannot be measured directly by instrumental means. Even the eye cannot measure it directly at night. In order to find out what properties of the atmosphere can be used as an indirect means of determining visibility it is necessary to study the theory of visibility.

Theory of daylight visibility.—The theory put forward by Koschmieder[1] in 1924, and independently by Götz, has been checked experimentally from time to time and is now accepted as the best.

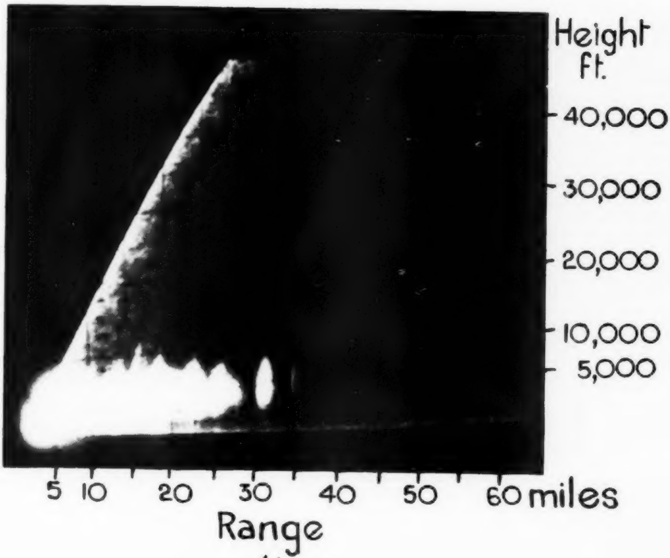
Koschmieder showed that the apparent brightness H_o of a black object viewed at a distance l against the horizon sky of brightness H_h is given by

$$H_o = H_h\,(1-e^{-\sigma l}) \qquad \ldots (1)$$

where σ is the extinction coefficient of the atmosphere. Both H_o and H_h are due to light scattered by the atmosphere, or the " air-light " as it is called.



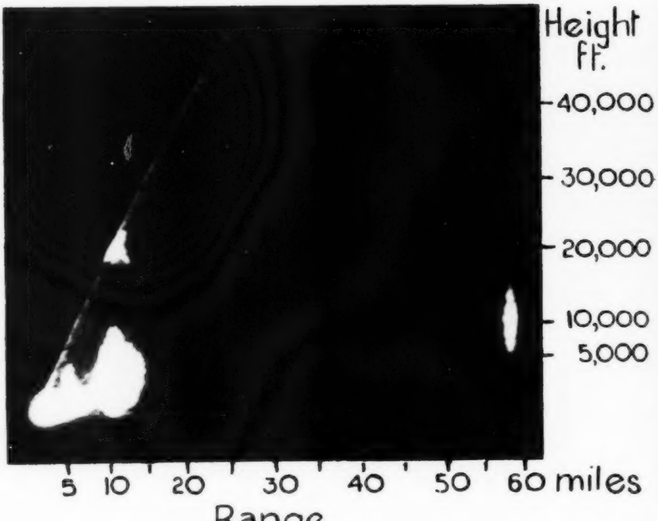
(a)



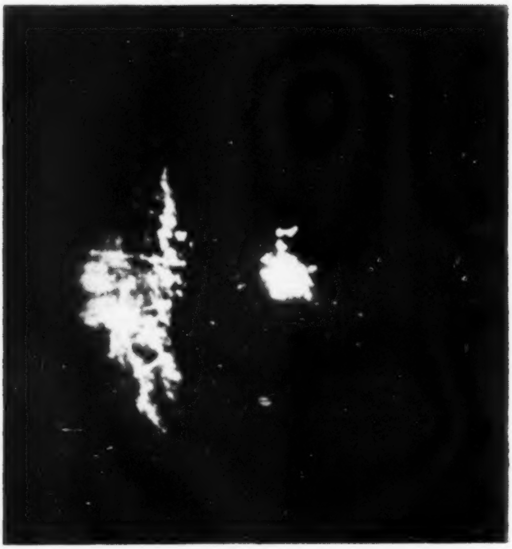
(b)

RADAR ECHOES FROM COLD FRONTS

(see p. 111)



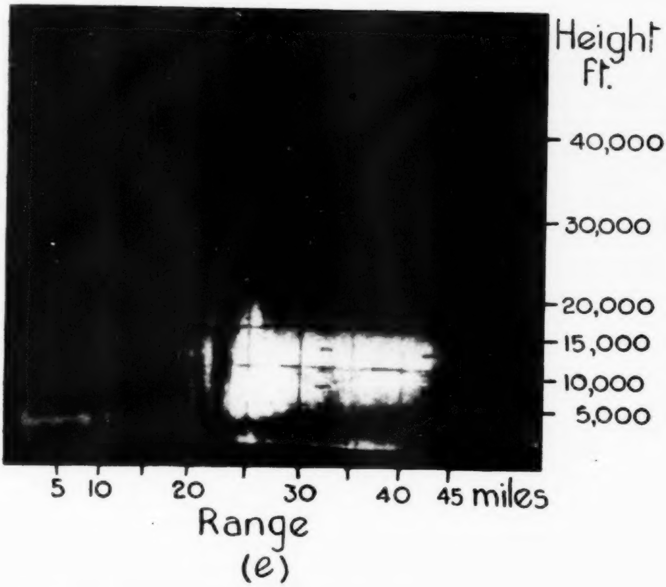
(c)

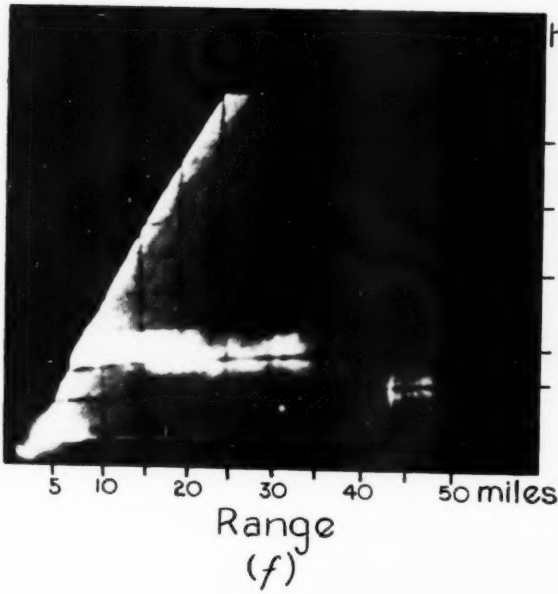


(d)

RADAR ECHOES FROM COLD FRONTS

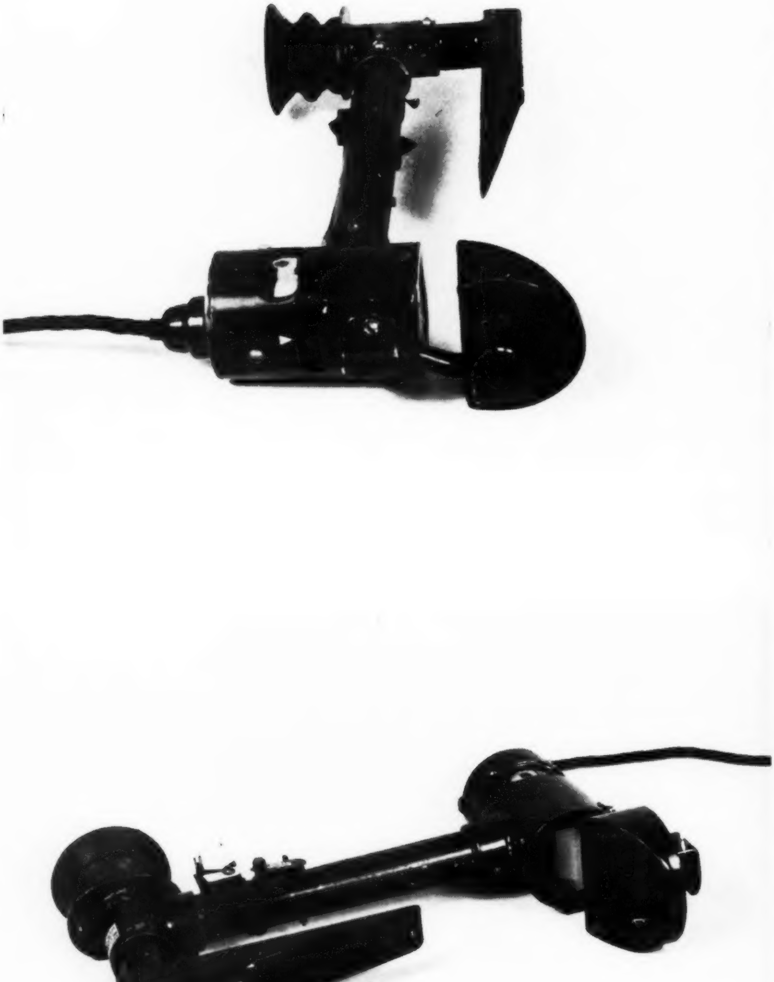
(see p. 111)





RADAR ECHOES FROM COLD FRONTS

(see p. 111)



BREWER-BEUTTELL VISIBILITY METER

(see p. 114)

In order to arrive at this result some simplifying assumptions are made, the most important being that the illumination and the coefficients of scattering and attenuation are constant along the line of sight from the eye to the object and to an infinite distance beyond.

For the contrast of the object against its sky background we have, from equation (1)

$$K = \frac{(H_h - H_o)}{H_h} = e^{-\sigma l}$$

If the object is only just visible, K becomes ϵ, the threshold of contrast, and l becomes V, the visibility, and we have

$$\epsilon = e^{-\sigma V}$$

or

$$V = \frac{1}{\sigma} \log_e \frac{1}{\epsilon} \qquad \text{.. (2)}$$

If ϵ is given the usual daylight value of 0·02 this becomes

$$V = \frac{3{\cdot}91}{\sigma} \qquad \text{.. (3)}$$

The scattering coefficient and the absorption coefficient do not appear in these expressions except as part of the extinction coefficient, which is their sum. Equations (1), (2) and (3) are therefore valid whatever the relative proportions of scatter and absorption, *i.e.* however much the atmosphere is polluted by absorbing matter such as smoke particles.

Daylight visual observations.—Extension of the theory shows that, if the object is not black, visibility is less, seriously so in fact for any but the darkest objects when illuminated by low sun. Experiment confirms this and shows that visibility varies also with the angular size of the object, if outside the range ½ to 5°, and from one observer to another (*i.e.* in equation (2) ϵ is not constant).

In order that visibility should be free from these variations and should represent only a state of the atmosphere, Löhle suggested the introduction of the concept " air-light range " which is the visibility computed for a black object and a contrast threshold of 0·02, *i.e.* V obtained from equation (3). Wright called this " standard visibility " and this term is generally used in Europe, although the necessary corrections to visual observations are not yet being made anywhere.

Visibility meters.—Turning now to the measurement of visibility instrumentally it is seen from equation (3) that the requirement is to measure σ. Instruments for doing this are divided into three main classes:—

I. Those measuring the air-light and using equation (1).

II. Those measuring σ directly from the attenuation of light from artificial sources.

III. Those measuring the scattering coefficient, which is equal to σ if absorption is negligible, *e.g.* at sea.

Visibility meters of class I.—Löhle's meter has two telescopes arranged to form images of the object and the adjacent sky, respectively, on the two parts of a Lummer-Brodhun photometric prism. The setting of an iris diaphragm in the sky telescope required to obtain a match gives H_o/H_h.

In Shallenberger and Little's meter[2], a thin prism is moved across an opening in a diaphragm over the object lens of a telescope until enough light from the sky is added to the normal images of object and sky to make the object only just visible. The prism setting gives H_o/H_h by means of an expression which unfortunately contains ϵ.

Waldram's "disappearance-range gauge" is almost identical, although developed independently.

These three daylight instruments are used for extrapolating for visibilities up to several times greater than the distance of the object.

Visibility meters of class II.—Middleton's "artificial-star" night-visibility meter[3] is arranged to produce an image of a built-in point source on the axis of a tube through which a distant light is viewed. A neutral wedge is used to reduce the apparent intensity of the distant light until a match is obtained. Matching of point sources is, however, difficult owing to the very rapid increase in sensitivity of the retina with distance from the central part or fovea.

The Gold night-visibility meter[4] is similar but has no comparison source. The wedge is used to reduce the apparent brightness of the distant light to the limit of perceptibility, *i.e.* to the visual threshold (of brightness). Conditions of observation are controlled so that the visual threshold is approximately constant for any one observer.

The Meteorological Office photo-electric meter uses a car headlamp to project a beam of light, and the attenuation of this is measured by means of two photo-cells, one close to the lamp and one 300 yd. away, which are connected in turn to a galvanometer. Very accurate alignment of lamp and photo-cell must be maintained. Calibration readings can be taken in weak daylight.

The American "transmissometer" is similar, but will work in full daylight and is arranged for distant recording.

Bergmann's meter[3] is also of the projector type but uses an interrupted light source so that steady currents due to daylight can be filtered out in the photo-cell circuits. It is a null method, the two photo-cells being connected in opposition. The beam is returned along its path by a corner reflector so that the two photo-cells are adjacent. This shortens the wiring but causes errors in fog due to the reinforcement of the return beam by back-scattered light from the outgoing beam. The instrument does not appear to have been developed, possibly because of its complication.

All the meters in this class are calibrated when visibility is good and known.

Visibility meters of class III.—In the Brewer-Beuttell meter[5] light from an opal window in front of a lamp is scattered through most angles along a 15-in. path into one half of the field of view of an eyepiece. The comparison half is provided by another opal window illuminated by the same lamp and its brightness is varied by means of an iris diaphragm to obtain a match. The instrument is hand-held and can be used only at night (see photograph facing p. 113).

The "Loofah hazemeter"[6] measures light scattered from a beam through an angle at which scattering is representative of total scattering. The scattered light is compared with the original source by means of a Lummer-Brodhun photometer. As the whole apparatus is contained in a light-tight box it can be used by day or night.

Accuracy.—The following rough estimates of errors show how the instruments described compare in this respect with direct visual observations, which are subject to errors of ±10 per cent. even in favourable circumstances.

With meters of the Shallenberger and Little type errors begin to exceed ±20 per cent. when visibility is 3 or 4 times the distance of the object used,

assuming that a " greyness " correction is applied. Errors begin to exceed ±20 per cent. with Middleton's meter when the ratio of visibility to base-line is about 5, with the Gold meter when it is 2 or 3 and with the British and American photo-electric instruments when it is 10 or 20. The Bergmann meter should be much more accurate. In general, errors are less at lower visibility but with the scatter meters errors of ±20 per cent. are likely over the whole working range.

When visibility is not uniform all methods are subject to sampling errors which are more noticeable the shorter the base-line used and are at a maximum with the scatter meters.

Oblique visibility.—Oblique or slant visibility presents more difficult problems, both theoretical, because conditions are generally not uniform in the vertical, and practical, because one end of the base-line must be in the free atmosphere.

Two methods of observation are being tried out at Farnborough. One of these, due to Green of the Royal Aircraft Establishment, employs visual observations on pyrotechnic flares fired to 200 ft. The other, being developed by the Meteorological Office, uses as a source the light scattered from a small part of an inclined searchlight beam. The illumination from this source is measured at two different distances by means of photo-cells placed on the ground.

The Director, opening the discussion, referred to the important aviation aspect of visibility measurement. First, a scientific property of the atmosphere, such as extinction coefficient, had to be measured, and secondly this had to be converted into the form required, for example oblique visibility for the approach or horizontal visibility for the landing. A special feature of night operations was that very bright lights could be used so making landings possible in lower visibilities than by day.

Mr. Bibby asked if we needed to measure visibility to an accuracy greater than that of daylight visual observations. With regard to standard visibility he suggested that this be based not upon the unattainable black object but upon the average dark object of albedo 10 per cent. He thought we should reject the falsely high estimates of visibility obtained with the rising or setting sun directly behind the object, a situation in which, he pointed out, Koschmieder's theory is not valid. A difficulty with the photo-electric meter was that the regular calibrations required to ensure accuracy were sometimes interrupted for long periods owing to poor visibility. The searchlight type of oblique-visibility meter was being modified for daylight use by the provision of a modulated light source.

Mr. G. J. W. Oddie said he had hoped for advice on desirable accuracy from the synoptic and aviation people present. The objection to relating standard visibility to a grey object was that visibility could then depend on direction of observation even if the atmosphere were homogeneous. The photo-electric meter could be calibrated in poor visibility well enough to keep it in use for similar or lower visibilities.

Mr. Waldram (General Electric Company Research Laboratories, Wembley) said that there was sometimes confusion between meteorologist and user because the term " visibility " was used for the meteorological visual range, for the disappearance range of a particular object and for the conspicuousness of a well-seen object. Speaking of the photo-electric meters he doubted the possibility of obtaining the claimed accuracy when extrapolating to visibilities 10 or 20 times

the base-line because errors in visibility were proportional to the degree of extrapolation. The scatter type of meter was useful in special circumstances such as in confined spaces or when the observer was moving. Movement incidentally improved sampling. The original Brewer-Beuttell meter had been made from odds and ends and therefore suffered from certain defects. It could undoubtedly be improved considerably. Meters of the Shallenberger and Little type might be very useful. Observations he had made with his own disappearance range gauge had shown a scatter of only ± 7 per cent. with visibilities 3 or 4 times the distance of the object used. With regard to air-light measurements he had with him, for inspection afterwards, a Schuil telephotometer which could be used for this purpose.

Mr. G. J. W. Oddie confirmed Mr. Waldram's statement that errors with photo-electric meters were proportional to the ratio of visibility to base-line. Nevertheless, errors given for the transmissometer were equivalent to ± 20 per cent. when this ratio was 16 while for Bergmann's meter Gurevich[9] claimed ± 20 per cent. for a ratio of 1,600.

Mr. Parker (Ministry of Civil Aviation) who had done much of the flight testing of the high intensity approach and runway lights at London Airport stressed the importance of reports of oblique visibility. With shallow fogs he had often seen the approach lights three miles away.

Mr. Collins (Building Research Station), who had been concerned with the development of the "Loofah hazemeter" when at the Admiralty Research Laboratory, said that night visibility should be specified in some way which made it directly usable. Meters of the scatter type had their uses when purely local measurements were required. Referring to sampling errors he mentioned that for good visibilities elevated objects had to be used and the visibilities observed did not represent surface conditions. To illustrate these and other points he described some trials carried out by the Admiralty in Cardigan Bay.

Mr. G. J. W. Oddie pointed out that, given equivalent daylight visibility, extinction coefficient could be obtained from the relation

$$\sigma = \frac{3{\cdot}91}{V}$$

Mr. B. C. V. Oddie said that while errors with the photo-electric meter might generally be within the limits claimed they were apt to become very large suddenly and without warning. Did this also happen with the Gold meter and did the Gold meter give good results with users other than the opening speaker?

Mr. G. J. W. Oddie thought that these sudden large errors with the photo-electric meter were caused by loss of alignment. The Gold meter was not easy to use but it was much more reliable than mere estimation based on experience of the general appearance of miscellaneous lights. All members of the London Airport staff who used the Gold meter regularly, including recently recruited assistants, obtained equally good results with it.

Mr. Waldram said that the alignment of photo-electric meters could be checked by replacing the photo-cell by an eyepiece. Habitual users of photo-electric devices found it necessary to check their operation regularly. The extinction principle used in the Gold meter was not popular with photometricians. The state of dark adaptation of the eye was changing continuously and it was also difficult to keep the image on the fovea. Power supply variations caused the candle power of the lights used to drop to half in extreme cases.

Mr. G. J. W. Oddie said that Mr. Waldram's suggested method of checking alignment could presumably not be applied to the projector. Referring to the Gold meter he showed a slide which indicated that for foveal vision dark adaptation was complete within two minutes and that the visual threshold for parafoveal vision, which for the first two minutes was about the same as that for foveal vision, continued to decrease for more than half an hour. Variations in the candle power of the light used did not have as great a percentage effect on the computed visibility as long as visibility was poor. (*Communicated later*: a drop in intensity by 50 per cent. would cause the computed visibility to drop from 1,000 yd. to 850 yd., if a light at 1,000 yd. were being used.) He thought the main reasons for difficulty in using the Gold meter were that between extinction and reappearance of the light the observer's gaze tended to wander and his focus to relax. A nearer or brighter light in the field of view helped in both respects, and did not affect the visual threshold.

Mr. Band thought that the sudden changes in the photo-electric meter were caused not by alignment troubles but by variations in the photo-cells or by mains fluctuations too big for the constant voltage transformer to compensate. At Ringway they had found the Gold meter to work surprisingly well.

Mr. J. L. Galloway said that Siedentopf had extended Koschmieder's theory and had found that the formulae should hold even when there is a linear change of extinction coefficient with distance. He found experimentally that cloud shadows caused errors of only about ± 10 per cent. Air-to-ground visibility was found to be a minimum towards the sun, instead of away from the sun as with horizontal visibility of a grey object in uniform conditions. Mr. Galloway thought that at some stations it was difficult to pick out the visibility lights from others when using the Gold meter. He pointed out that nearby buildings might seriously affect the indications of the photo-electric meter.

Mr. G. J. W. Oddie mentioned some recent experiments[7] carried out in the United States which confirmed Siedentopf's conclusion that lighting variations usually had little effect on visibility. If visibility lights were not conspicuous enough their candle power should be increased so that when the Gold meter was used other lights would disappear first.

Mr. Lane (Admiralty Research Laboratory) outlined an investigation which the Admiralty was about to start into the effect of size, shape and greyness of objects on their visual range.

Mr. Gold emphasised that daylight visibility was the best single form for stating both day and night visibilities as for night use conversion to visual range of lights was simple. He also stressed the importance of keeping visibility meters clean, and suggested that dirt might be responsible for the changes in photo-electric meters. For most practical purposes he thought that meters using a long base-line were superior to those which, like the scatter types, gave purely local visibility.

The Director, in closing the discussion, thanked the visitors who had contributed so much to the value of the discussion. Aviation, he said, presented special problems and it was not satisfactory to express visibility in the same way for all purposes. The aim must be for each meteorological office to be able to convert equivalent daylight visibility into the form required locally. With regard to slant visibility our first task was to investigate the variation of horizontal visibility with height.

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METEOROLOGICAL RESEARCH COMMITTEE

The eighth meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on February 2, 1950.

The Chairman's report to the Committee was considered and the Sub-Committee also drew up recommendations for revision of that part of the Research Programme dealing with synoptic and dynamical matters.

A paper by Mr. J. M. Craddock*, dealing with the warming of cold air masses over the sea to the north-west of the British Isles, was discussed.

**Met. Res. Pap., London*, No. 526, 1949.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

PROFESSIONAL NOTES

No. 98—*Rainfall in east Scotland in relation to the synoptic situation.* By R. F. M. Hay, M.A.

Rainfall in east Scotland was related with the synoptic situation, using Aberdeen hourly data and *Daily Weather Reports* for 1926–30. Depressions yielding falls of > 25 mm. at Aberdeen moved from between west-south-west and south-east on tracks converging to a region 60–125 miles south of Aberdeen. Less than 10 per cent. of these falls were accompanied by thunder. Simplified " tracks " were devised and average rainfalls estimated for depressions moving on them. The largest number of systems yielding falls > 3 mm. moved on tracks ("A" and " B ") from the Bay of Biscay north-north-east to a position off east Scotland and from Galway east-north-east through north England. Maximum average seasonal yields of rain from single depressions on most tracks occur in autumn (track B, 13 mm.) but for track C (east moving south of Aberdeen) the seasonal distribution is different, 11 mm. in summer and 4 mm. in winter. The chance of rainfall exceeding 10 mm. from a single system only reaches 40 per cent. with tracks A and B.

Warm occlusions moving north-eastwards mainly in autumn and winter produce the larger rainfalls at Aberdeen. Cold fronts yield little rain unless accompanied by considerable troughs. Results found were of some assistance

in forecasting amounts of falls in Edinburgh in summer except in thundery situations, and were also generally applicable to other areas of east Britain.

The general results agree with theoretical considerations by several workers on rainfall and air movement near centres of depressions. Vertical moisture distribution also influences rainfall in these situations; most cases with Duxford tephigrams available showed " latent instability " with high humidities below 5,000 ft., above 5,000 ft. the tropical air was stable but usually very moist.

ROYAL METEOROLOGICAL SOCIETY AND INSTITUTE OF PHYSICS

A joint meeting was held in the Royal Institution on November 23, 1949, the subject for discussion being " The physics of atmospheric pollution ". It was opened by Dr. A. R. Meetham, who was until recently in charge of atmospheric pollution investigations at the Fuel Research Station, Greenwich.

He began by describing the methods of measuring atmospheric pollution, and gave a survey of the results obtained. The impurities formed by the burning of coal (ash, carbonaceous matter and sulphur dioxide) are naturally most abundant in industrial areas, while chlorides are found mostly near the coasts, indicating an origin in sea spray.

Approximate figures were given for the total deposition of the various impurities on Great Britain, the total being several million tons per year. These figures were compared with the estimated total output of impurities by coal burning, and considerable discrepancies between the two sets of figures were found.

Dr. Meetham proceeded to examine the causes of these. Ash appears to be over-estimated by the deposit gauges, which may be explained by the " ash " including a quantity of dust blown up from the ground. The quantity of ash emitted by chimneys is also subject to a good deal of uncertainty.

On the other hand, carbonaceous matter (soot and smoke) and sulphur dioxide are deposited in the gauges in much smaller amounts than are emitted by chimneys. This can be explained partly by the amount blown away to sea, but rough calculations showed that this could not account for all the discrepancy. The remainder is probably due to the fact that natural surfaces such as grassland present a much greater surface to the air than their nominal area, and so collect a correspondingly bigger deposit of pollution.

The chief points emphasised in the subsequent discussion were the especially damaging effect of sulphur dioxide in the air, and the advantage (to the user as well as the community) of domestic grates designed to burn smokeless fuel. Mr. Gold pointed out that some of Dr. Meetham's figures implied a considerable influx of smoke from outside this country, *e.g.* from France. Dr. Penman suggested that if any steps were to be taken to measure this it would be useful at the same time to check the migration of aphides from France to England.

Mr. Bonacina recalled smoke-laden fogs in London in the nineties, and asked whether there were any measurements of the obvious improvement since then. Dr. Meetham said that pollution measurements only started in 1914, but they showed a marked reduction of pollution between that year and 1922.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of the Society was held on January 25, 1950, with the President, Sir Robert Watson-Watt, F.R.S., in the chair.

The President presented the Annual Report of the Council and announced the awards of Buchan Prizes and of the H. R. Mill Medal recently founded for recognition of research into rainfall problems. The Buchan Prizes were awarded to Dr. R. C. Sutcliffe and Mr. C. H. B. Priestley for their recent contributions to dynamical meteorology, and the H. R. Mill Medal to Dr. H. R. Mill, former Director of the British Rainfall Organization.

The President then delivered his Presidential Address on the " Evolution of Meteorological Institutions in the United Kingdom ". He opened his address by briefly describing the work of those British societies and institutions which had commenced the development of meteorology in the nineteenth century and went on to enumerate those bodies now actively engaged in the study and practice of the science. The work of learned societies, universities, private enterprise and the Meteorological Office received recognition. The President said his main object was not to describe the history of progress in meteorology in this country, which would be fully dealt with in the forthcoming Centenary celebrations, but rather to put forward what he conceived to be the primary objects of a Society composed of those who, as amateurs in the best sense, took a delight in the science in relation to the professional meteorological institutions. These objects were, he considered, the stimulation of the flow of trained physicists into meteorological work and encouragement of and assistance to them in their professional work. These objects would be fulfilled by vigorous development of the Society's facilities for the discussion and publication of meteorological research, and especially by facilitating discussions with those for whom, from directors of aviation companies to agriculturists, meteorological information was essential for efficient work. He drew especial attention to the need for further research into the application of meteorology to biological problems of all kinds. Finally, he analysed parts of the Annual Report of the Director of the Meteorological Office for the year 1948–49, and appraised the work of the Office in both research and the provision of meteorological information with special mention of its needs in staff and money.

LETTERS TO THE EDITOR

Extremes of humidity

The following extremes of humidity may be of interest. They were recorded by a hair hygrograph in a Stevenson screen during July 1949 at Swimbridge, north Devon, 450 ft. above M.S.L.

Date	Time	Dry bulb	Relative humidity	Vapour pressure
	G.M.T.	°F.	%	mb.
July 11	1600	84·5	14	6·0
July 12	1600	88·8	16	7·6
July 26	1300	73·8	68	19·5
July 27	0600	64·8	93	19·9

The low humidity on July 11 and 12 caused fir-cones of a maritime pine to explode with a noise similar to that made when a good-sized stick is thrown into a tree. These two readings are the lowest ever recorded by me.

However, the high readings were exceeded on July 31, 1938, when I recorded a vapour pressure of 22·9 mb. at 1800 at South Petherton, Somerset.

J. M. BRIERLEY

The Old Cyder House, Bydown, Swimbridge, N. Devon, August 1, 1949

Long periods with sunshine every day at Newquay

At Newquay, Cornwall, during the past 56 years, periods of 66 consecutive days or more with measurable sunshine were recorded in six years, namely:—

	days
1911, July 1 to September 11	73
1915, June 28 to September 14	79
1919, May 2 to July 20	80
1924, March 29 to June 2	66
1948, April 1 to June 5	66
1949, June 12 to September 17	98

Only two of the years mentioned above, namely 1911 and 1949, can safely be classified as good summers, and the following are the longest periods with measurable sunshine on consecutive days during some of the previous good summers:—

		days			days
1921	March 29 to May 10	43	1940	May 6 to June 21	47
	June 5 to July 22	48		July 17 to September 13	59
1933	June 3 to July 12	40	1941	August 16 to September 26	42
	August 18 to October 17	61			
			1947	April 7 to May 16	40
1934	May 22 to June 20	30		June 18 to July 19	32
	June 24 to July 31	38		July 29 to September 13	47
	August 13 to September 18	37			

F. J. HARRIS

10 Trelawny Road, Newquay, Cornwall, November 16, 1949

NOTES AND NEWS

Aircraft struck by lightning

On three occasions during the month of May 1949, Hastings aircraft from Dishforth were struck by lightning in circumstances that seem worthy of remark. Although weather conditions on all three occasions were unstable and local thunderstorms had been or were reported subsequently, at the times when the aircraft were struck no storms were observed in their vicinity, and radio atmospherics were not sufficiently excessive to suggest to the aircrew that there was a potential danger. Mr. T. H. F. Gifford, meteorological officer at Dishforth, has obtained the following information from the aircrews.

On May 15, an aircraft homeward bound from Malta was over northern France at 1100 G.M.T. flying at 6,500 ft. There were large broken cumulus clouds with bases at 4,000 ft. and tops extending to 14,000 ft. but no precipitation was observed. Turbulence was assessed as moderate, and radio atmospherics were not sufficient to suggest that the trailing aerial should be wound in. There was a loud report, a blue flash appeared to travel the length of the aircraft, and the trailing aerial was burnt off inside the aircraft at the winch. No other damage was sustained and the compasses were not affected. The synoptic situation at 0900 G.M.T. on that day showed a slow-moving thundery depression in the Toulouse area with thundery rain and local thunderstorms widespread over southern France and the Massif. Altocumulus castellatus was reported as far north as latitude 48°N. and scattered showers and large

cumulus, base 3,000 ft., were reported over northern France. The situation was such as to suggest that a real risk of thunderstorms did not extend to northern France at that time of the day.

On the following day, May 16, another aircraft, also homeward bound from Malta, was just south of the central Massif in France, flying at 14,500 ft. At 1000 G.M.T. a flash of lightning carried away the trailing aerial, and the starboard outer motor stopped temporarily. There was no precipitation observed at the time but there were large cumulus clouds, base and tops unspecified, with patches of layer cloud. The general weather situation was similar to that of the previous day. The thundery depression had moved into the Gulf of Lions and cloud over the Massif was reported as large cumulus, with local thunder over the northern fringe at 1200 G.M.T. Presumably the aircraft was caught in the developing thundery conditions.

The third incident occurred in England over the Pennines, when an aircraft flying on a course from Dishforth to Shawbury was in cloud at 6,000 ft. at 1530 G.M.T. The aircraft had entered the cloud only very shortly before the lightning strike occurred, and while there were frequent hail showers radio atmospherics were not unduly pronounced. The flash appeared to originate from ahead of and above the cockpit and no damage appeared to have been sustained. Subsequent ground inspection showed that a hole had been punctured in the leading edge of the starboard main plane near the outer motor, a bolt of one of the inspection panels had been sheared and the panel partly ripped off. Another aircraft flying the same course 3 minutes in the rear flew through hail showers but radio atmospherics were not sufficient to occasion comment. At 1500 G.M.T. on that day the Pennines were in a north-westerly polar maritime air stream ahead of a developing ridge over Ireland. Cloud forms were of the convective type and scattered showers were reported at ground level. The 1500 G.M.T. Liverpool ascent was already showing signs of subsidence above 700 mb. with a freezing level at 6,000 ft. The forced ascent of air over the Pennines was presumably adding to its instability in the lower layers.

The conclusion to be drawn from these three incidents appears to be that, although convection conditions may not have developed to the stage where thunderstorms are observed, an aircraft can concentrate the atmospheric electric field in its immediate vicinity to a degree sufficient to cause the break-down electric force of 10,000 v./cm. to be exceeded, thereby initiating a discharge.

METEOROLOGICAL OFFICE
38 GROUP, R.A.F.

REVIEW

Regression of climatic elements on latitude longitude and elevation in India. By P. Jagannathan. *Sci. Notes met. Dep. India, Delhi*, **10**, 1948, No. 121. Part I—Mean temperature, pp. 83–105. No. 122. Part II—Diurnal range of temperature, pp. 107–118. Size: 10 in. × 7 in. *Illus.* Part I—*Rs.* 2/2/- or 3*s.* 6*d.* and Part II—*Rs.* 1/2/- or 1*s.* 9*d.*

Jagannathan, in the first of a series of papers on the regression of climatic elements, has achieved for India what Hopkins* did for the Canadian prairies, namely, the computation of partial regressions of average temperatures on latitude, longitude and altitude for a wide selection of meteorological stations. Jagannathan bases his regressions for India as a whole upon 167 stations.

*HOPKINS, J. W.; Agricultural meteorology: correlation of air temperatures in central and southern Alberta and Saskatchewan with latitude, longitude and altitude. *Canad. J. Res. Ottawa*, C.**16** 1938, p. 16

He also divides these into roughly equal groups characterising four main climatic regions. For each of these four regions and for India as a whole, partial regression coefficients for the twelve calendar months and the year are listed with their standard errors; and the corresponding multiple correlation coefficients show that, for the most part, the labour has been worth while. The reviewer was disappointed, however, to find that none of the correlation coefficients of temperature separately with latitude, longitude and altitude were given. Without such coefficients it is difficult to get any clear idea as to what proportion of the average temperature variation is due to these factors. The addition also of mean values of all four variates would have been extremely useful, enabling other investigators to compute rapidly estimates of average temperature at places in India for which long-period normals are not available

The regression coefficient of temperature on altitude of station is seen to fluctuate about a mean value roughly equivalent to the average lapse rate in the free air (3°F./1,000 ft.). On recalculating for different altitude ranges, however, Jagannathan finds that a definite relation between height and temperature exists only for high altitude stations—those in the height ranges exceeding 1,000 ft.

Part II is similar to Part I, with average temperature replaced by the average difference between monthly mean maximum and minimum temperatures, and it suffers from the same omissions. Here the fit of the regression equations is not nearly so good; the dependence of range of temperature on altitude is non-significant in three of the four regions and, in the opinion of the reviewer, the inclusion of this third independent variable is scarcely worth the extra labour of computation that it must have involved. Linearity of regression is assumed throughout.

The author is to be congratulated on the achievement of such comprehensive regression analyses as those described in the two papers under review. His comments on the results are interesting and can be easily understood by the non-statistician.

N. CARRUTHERS

METEOROLOGICAL OFFICE NEWS

Air meteorological observers.—Since 1946 the Royal Air Force have provided observers for meteorological reconnaissance aircraft from pilots, navigators and air gunners: a return is now being made to the wartime practice of recruiting air meteorological observers from the staff of the Meteorological Office and scientific assistants who have begun, or are about to begin, their whole-time national service have been invited to volunteer. So the flying badge of air meteorological observer, well known by 1945 to the R.A.F. and the public, will soon be seen again, and valuable air experience will not be lost to the Meteorological Office when the observers complete their tour of duty.

Appointment as A.E.O.—Established scientific assistants will be interested to learn that the upper age limit for them has been raised from 25 to 30 in the 1950 competition for appointment as assistant experimental officers.

Married quarters.—Some additional quarters have been allocated to Meteorological Office staff at overseas stations. Three families will probably be accommodated at Changi (Singapore) by the end of the summer.

Central Forecasting Office.—In February the Central Forecasting Office celebrated the tenth anniversary of its inauguration at Dunstable. Sixteen

members of the original staff of about one hundred are still serving at C.F.O., though one or two have seen duty elsewhere in the meantime.

In recent months the main forecast room in the original wartime hut accommodation of C.F.O. has been much improved by a new lighting installation, by removal of the partition which separated the surface and upper air work, and by the introduction of newly designed double-sided charting slopes. Now that the Forecast Research Division has its own new Napier Shaw Laboratory across the way (see Meteorological Office News, March 1950), more accommodation has become available for the other staffs at C.F.O., so that now the scientific and experimental officers and assistants each have their own rooms for study and non-routine work on normal duty periods.

Beaufort letter g.—It is odd that Beaufort, though an Admiral, made no provision for recording gales in his well-known letter notation: this has now been remedied. To make it easy for people who consult the *Daily Weather Report* to pick out occasions of gale, the meaning of g, hitherto allocated to "gloom", has been altered from March 1, 1950. g and G now have the following meanings:—

g = gale (Beaufort force 8 or 9) and G = whole gale (force 10 or more),

the wind force in each case being maintained for a period of not less than ten minutes.

Thunderstorm location in Malta.—Using a radio teleprinter for communication, trials have recently been made of operating a thunderstorm-location ("sferic") apparatus in Malta in conjunction with the British network. It has been found that the same lightning flashes can be identified in the United Kingdom and in Malta, and the long base-line allows storms in the Mediterranean area, central Europe and eastern Atlantic to be located with improved accuracy.

Experimental transmission of weather charts.—Using a facsimile apparatus and the ordinary telephone line transmissions of charts have been tried between C.F.O. and London Airport. A line chart 20 cm. × 13 cm. can be transmitted in about two minutes; for meteorological purposes an apparatus is needed which can reproduce a chart not less than 50 cm. × 40 cm. with clear detail.

A daylight illumination recorder, similar to the one which has been in use at Kew Observatory since 1947 has been installed on the roof of the Meteorological Office, Kingsway. It gives a continuous record of daylight illumination as it appears to the human eye, the eye being a selenium photocell, and the recorder a galvanometer in the forecast room. The purpose is to assess brightness in varying conditions of cloudiness, so that forecasts of cloud thickness and density can ultimately be given in terms of daylight brightness.

Ocean Weather Ships.—Following one of the decisions of last year's I.C.A.O. Conference in London on North Atlantic weather stations, by which the Netherlands provides one ship for occasional relief of the British ships on Station J (and also the French ships on Station K), the Netherlands' O.W.S. *Cumulus* will occupy Station J from April 15, in rotation with the British ships. The observations from *Cumulus* will be sent direct to C.F.O. as they are from the British ships. This co-operation between seamen and meteorologists of the two countries is now traditional, and *Cumulus* will be warmly welcomed when she arrives on station.

Magazines for Weather Ships.—Books or periodicals are very much appreciated by the ships' companies of O.W.S. Will readers of these columns who have any to spare, please send them to the Meteorological Office (M.O.1), Headstone Drive, Harrow, Middlesex, or to the Shore Captain, Ocean Weather Ship Base, Great Harbour, Greenock ?

The Meteorological Association, now three years old, will hold its annual general meeting at the refectory of the Imperial College at 6.15 p.m. on April 21; tea will be served from 5 p.m. The Association has arranged to hold its third reunion dance at Crosby Hall, Cheyne Walk, Chelsea, at 7.30 p.m., on Saturday May 13. Tickets (3*s.* 6*d.* single, 6*s.* double) may be obtained from the Treasurer, Mr. W. P. Osmond, 238 Sheen Lane, East Sheen, S.W.16. Details will shortly be announced about this year's summer outing which will be a visit to C.F.O., Dunstable, on Saturday September 16.

The primary object of the Association is to further good fellowship among members, and to maintain wartime friendships. Anyone who is, or has been, a full-time practising meteorologist, either as a member of the Meteorological Office or of H.M. Forces, can become a member, and is invited to apply to the Treasurer (address above); the annual subscription is the modest sum of 2*s.* 6*d.*

Social activities.—As these notes go to press, arrangements have been completed for the annual evening social for members of the staff, their wives and friends in Victoria Hall, Bloomsbury Square. The party has become a firmly rooted function because it is one of the few opportunities our widely scattered staff have for meeting old friends and making new ones. Any profits go to enable Meteorological Office teams to take part in inter-departmental sports events.

Retirement.—Mr. S. F. Witcombe retired from duty with the Meteorological Office on March 31, after 34 years' service. Mr. Witcombe's first contact with meteorology was in the Meteorological Section, Royal Engineers, in 1916; in the course of his duties during the latter part of the 1914–18 war, he made many ascents in a manned balloon to make meteorological observations. Since 1918 Mr. Witcombe has spent most of his time on forecasting at M.O. Headquarters, Croydon, and Gloucester; more recently he has been examiner in meteorology for navigation certificates for pilots.

His many friends in the Meteorological Office and in Civil Aviation will always remember his outstanding work as a forecaster, his quiet imperturbable manner, and his readiness to help his younger and less experienced colleagues. The Meteorological Office suffers a loss with " Wit's " retirement, and wishes him well in the years ahead.

WEATHER OF FEBRUARY 1950

Mean pressure was between 1020 and 1025 mb. over an area that included part of Canada and most of the United States, and which extended across Bermuda and the Azores to Spain, Morocco and Algeria. It was below 1000 mb. from southward of Greenland across Iceland and northern Scotland to the west coast of Norway, and below 990 mb. over a small part of this region about 300 miles south-westward of Iceland. It was below normal over western Europe north of about latitude 43°N., but above normal around the Mediterranean and over most of Canada and the United States.

In the British Isles the weather was unsettled and wet, exceptionally so over England and Wales, where it was the wettest February since the record wet month of 1923, although February 1937 was almost as wet. Mean temperature exceeded the average in the south but was slightly below the average in the north.

The morning of the 1st was cold and some low minimum temperatures were registered; for example, 15°F. at Leeming and 11°F. at Eskdalemuir. Thereafter, a deep depression was centred south-east of Greenland, while troughs or secondary depressions passed over or near the British Isles causing frequent and heavy rainfall (2·43 in. at Treherbert, Glamorgan, and 2·35 in. at Ashburton, Devon, on the 1st and 2·29 in at Borrowdale, Cumberland, and 2·18 in. at Cricket St. Thomas, Somerset, on the 2nd). The main depression moved little but became less deep. On the 6th another deep depression in mid Atlantic moved to south-west Iceland and on the 7th a trough of low pressure crossed the British Isles giving further rain or showers. Subsequently, new disturbances developed over the Atlantic and associated troughs, crossing this country, caused more rain which was heavy locally at times; for example, in Wales on the 9th, when 2·65 in. was registered at Lake Vyrnwy. On the 11th a complex depression moved across Scotland and was followed on the 12th and 13th by another disturbance which crossed Ireland and England; rain occurred daily in most areas. From the 13th to 16th the Azores anticyclone moved east-north-east to the Alps, while another deep Atlantic depression moved north-east and troughs or small secondary depressions affected the weather of the British Isles; mild weather, with heavy local rain, prevailed. Rainfall amounted to 3·38 in. at Fort William, 3·00 in. at Ardgour, Argyllshire, and 2·08 in. at Loch More, Sutherland, on the 16th. The frequent heavy rains of the first sixteen days caused considerable flooding in some districts. Much of England came under the influence of the continental anticyclone from the 15th to 18th and experienced a mainly dry spell so that the flood subsided. This latter period was very mild and temperature reached 61°F. at Mildenhall and London Airport and 59°F. at Kew Observatory and some other stations in the southern half of the country on the 17th. Further rain occurred, however, on the 19th and 20th. Subsequently, high pressure was established over France, with a wedge extending over England and a short spell of mainly fair weather occurred, but still more rain fell on the 23rd when a trough crossed England and Wales.

On the 24th and 25th a depression off south-west Ireland moved south-east and then east over northern France and colder NE.—N. winds prevailed; substantial amounts of snow fell in some northern districts, and smaller falls in the south-east, which soon melted. A ridge of high pressure followed, which dominated eastern and Midland districts until the end of the month, with keen to hard frosts in many places.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales	63	12	+2·3	220	+3	103
Scotland	56	6	−1·2	127	+1	134
Northern Ireland ..	60	18	−0·5	117	+3	98

RAINFALL OF FEBRUARY 1950

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ..	3·30	198	*Glam.*	Cardiff, Penylan ..	6·97	237
Kent	Folkestone, Cherry Gdn.	3·99	197	*Pemb.*	St. Ann's Head ..	8·19	292
„	Edenbridge, Falconhurst	5·92	268	*Card.*	Aberystwyth	5·07	204
Sussex	Compton, Compton Ho.	6·69	254	*Radnor*	Tyrmynydd	10·29	196
„	Worthing, Beach Ho.Pk.	4·33	219	*Mont.*	Lake Vyrnwy	13·13	288
Hants	Ventnor, Roy. Nat. Hos.	5·03	240	*Mer.*	Blaenau Festiniog ..	13·30	163
„	Bournemouth	5·34	224	*Carn.*	Llandudno	5·29	271
„	Sherborne St. John ..	4·44	203	*Angl.*	Llanerchymedd ..	5·07	200
Herts.	Royston, Therfield Rec.	3·23	210	*I. Man.*	Douglas, Borough Cem.	4·68	147
Bucks.	Slough, Upton	3·85	227	*Wigtown*	Port William, Monreith	3·75	122
Oxford	Oxford, Radcliffe ..	4·09	250	*Dumf.*	Dumfries, Crichton R.I.	3·02	92
N'hant.	Wellingboro', Swanspool	3·70	230	„	Eskdalemuir Obsy. ..	6·37	129
Essex	Shoeburyness	2·43	198	*Roxb.*	Kelso, Floors	3·07	181
Suffolk	Campsea Ashe, High Ho.	2·54	184	*Peebles*	Stobo Castle	4·49	163
„	Lowestoft Sec. School ..	2·29	164	*Berwick*	Marchmont House ..	2·57	124
„	Bury St. Ed., Westley H.	3·06	204	*E. Loth.*	North Berwick Res. ..	1·72	110
Norfolk	Sandringham Ho. Gdns.	3·98	241	*Midl'n.*	Edinburgh, Blackf'd. H.	2·68	161
Wilts.	Bishops Cannings ..	4·98	235	*Lanark*	Hamilton W. W., T'nhill	4·47	154
Dorset	Creech Grange.. ..	5·56	195	*Ayr*	Colmonell, Knockdolian	3·38	88
„	Beaminster, East St. ..	7·06	234	„	Glen Afton, Ayr San ..		
Devon	Teignmouth, Den Gdns.	6·40	241	*Bute*	Rothesay, Ardencraig	4·78	119
„	Cullompton	6·13	220	*Argyll*	L. Sunart, Glenborrodale	6·38	106
„	Ilfracombe			„	Poltalloch	6·49	151
„	Okehampton, Uplands	10·03	236	„	Inveraray Castle ..	9·70	143
Cornwall	Bude, School House ..	4·93	197	„	Islay, Eallabus ..	5·36	128
„	Penzance, Morrab Gdns.	7·31	219	„	Tiree	5·16	150
„	St. Austell	8·51	222	*Kinross*	Loch Leven Sluice ..	3·09	109
„	Scilly, Tresco Abbey ..	6·58	236	*Fife*	Leuchars Airfield ..	1·81	103
Glos.	Cirencester	6·55	290	*Perth*	Loch Dhu	9·43	127
Salop.	Church Stretton ..	5·50	235	„	Crieff, Strathearn Hyd.	3·99	113
„	Cheswardine Hall ..	5·07	285	„	Pitlochry, Fincastle ..	5·35	182
Worcs.	Malvern, Free Library	4·66	259	*Angus*	Montrose, Sunnyside ..	2·21	120
Warwick	Birmingham, Edgbaston	5·28	312	*Aberd.*	Braemar	3·99	140
Leics.	Thornton Reservoir ..	4·22	253	„	Dyce, Craibstone ..	3·40	148
Lincs.	Boston, Skirbeck ..	3·20	219	„	Fyvie Castle	3·65	163
„	Skegness, Marine Gdns.	3·41	223	*Moray*	Gordon Castle	2·38	124
Notts.	Mansfield, Carr Bank ..	4·58	237	*Nairn*	Nairn, Achareidh ..	1·82	112
Derby	Buxton, Terrace Slopes	7·14	190	*Inverness*	Loch Ness, Garthbeg ..		
Ches.	Bidston Observatory ..	3·99	239	„	Glenquoich	12·13	117
Lancs.	Manchester, Whit. Park	4·03	210	„	Fort William, Teviot ..	11·13	148
„	Stonyhurst College ..	5·22	156	„	Skye, Duntuilm ..	5·49	119
„	Blackpool	4·21	188	*R. & C.*	Tain, Tarlogie House ..	2·35	103
Yorks.	Wakefield, Clarence Pk.	4·26	249	„	Inverbroom, Glackour ..	5·26	103
„	Hull, Pearson Park ..	3·61	217	„	Applecross Gardens ..	5·79	115
„	Felixkirk, Mt. St. John	3·20	189	„	Achnashellach	7·43	108
„	York Museum	3·37	223	„	Stornoway Airfield ..	3·87	91
„	Scarborough	3·08	183	*Suth.*	Loch More, Achfary ..	7·17	109
„	Middlesbrough.. ..	2·46	189	*Caith.*	Wick Airfield	1·90	84
„	Baldersdale, Hury Res.	6·73	224	*Shetland*	Lerwick Observatory ..	5·09	161
Norl'd.	Newcastle, Leazes Pk. ..	3·58	234	*Ferm.*	Crom Castle	4·01	137
„	Bellingham, High Green	4·41	174	*Armagh*	Armagh Observatory ..	2·78	125
„	Lilburn Tower Gdns. ..	3·15	158	*Down*	Seaforde	4·27	140
Cumb.	Geltsdale	4·81	185	*Antrim*	Aldergrove Airfield ..	2·72	113
„	Keswick, High Hill ..	6·77	137	„	Ballymena, Harryville..	3·18	99
„	Ravenglass, The Grove	4·77	155	*L'derry*	Garvagh, Moneydig ..	2·98	95
Mon.	Abergavenny, Larchfield	7·00	220	„	Londonderry, Creggan	3·60	113
Glam.	Ystalyfera, Wern House	10·52	205	*Tyrone*	Omagh, Edenfel ..	3·47	116

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, OCTOBER 1949

Stations	Pressure: Mean of day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Temperatures: Mean values Min.	Temperatures: Mean values ½ Max. and Min.	Temperatures: Mean values Diff. from normal	Temperatures: Mean values Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Daily mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.		hr.	%
London, Kew Observatory	1016·0	+1·8	73	30	61·5	47·7	54·6	+3·6	51·6	87	6·0	5·24	+2·54	14	3·7	35
Gibraltar	1020·3	+3·1	82	54	75·4	63·7	69·5	+3·1	65·0	81	4·3	0·00	—	0	7·7	68
Malta	1018·5	+2·5	82	58	74·5	63·8	69·1	−1·8	65·9	74	4·6	7·32	—	14	7·0	62
St. Helena	1017·3	−0·5	70	53	63·3	54·1	58·7	0·0	55·0	98	7·9	2·24	+0·53	17	—	—
Lungi, Sierra Leone	1012·8	—	90	69	85·3	71·5	78·4	—	73·8	89	6·0	12·66	—	20	6·8	57
Lagos, Nigeria ..	1012·0	+1·0	89	67	86·4	70·0	78·2	−1·5	76·8	85	6·6	10·09	—	17	6·4	54
Kaduna, Nigeria ..	1010·4	—	93	59	88·5	65·6	77·1	−0·6	70·9	71	5·3	1·62	−1·13	6	8·0	67
Chileka, Nyasaland	1015·9	+0·3	95	59	89·6	67·1	78·3	+0·2	64·2	50	1·5	0·79	−0·27	2	8·6	69
Lusaka, Rhodesia ..	1011·0	+0·4	99	57	92·5	64·1	78·3	+2·0	60·2	36	0·9	0·01	−0·50	1	9·9	80
Salisbury, Rhodesia	1014·6	+0·3	90	72	83·6	58·2	70·9	+0·6	56·7	44	1·3	0·09	−1·06	2	9·8	78
Cape Town	1016·7	−0·7	93	43	71·5	54·0	62·7	+1·5	52·7	59	3·7	1·04	−0·61	8	—	—
Palmietfontein, S. Africa	1015·3	—	87	39	79·3	53·5	66·4	—	54·7	58	3·0	2·65	—	10	9·3	—
Mauritius	1018·7	+0·5	85	58	80·4	63·7	72·1	−0·6	63·7	62	4·4	0·61	−1·06	12	7·2	58
Calcutta, Alipore Obsy.	1008·4	−1·1	94	69	91·1	76·5	83·8	+4·5	78·8	76	3·6	3·60	−1·30	12	7·3	63
Bombay	1008·7	−1·1	95	71	88·7	76·9	82·8	+0·4	77·4	80	4·2	1·35	−0·32	7	7·6	65
Madras	1007·7	−1·2	97	74	91·3	76·9	84·1	+1·8	76·7	77	4·3	3·45	−7·70	12	7·5	64
Colombo, Ceylon ..	1010·2	+0·2	87	73	85·3	76·1	80·7	+0·2	71·1	59	5·3	13·04	−0·32	16	6·6	55
Singapore	1009·8	+0·1	90	73	87·5	76·4	81·9	+0·8	76·6	80	6·7	3·19	−4·88	14	7·1	59
Hongkong	1012·4	−1·3	91	68	81·7	72·7	77·2	+0·3	70·1	71	—	3·06	−1·88	6	6·0	52
Sydney, N.S.W. ..	1010·9	−3·9	89	44	76·0	59·9	67·9	+4·3	60·9	60	4·0	1·51	−1·34	9	8·2	63
Melbourne	1007·8	−7·0	80	37	66·7	49·1	57·9	+0·2	52·6	63	6·6	5·06	+2·43	24	3·9	30
Adelaide	1009·2	−6·8	87	43	68·5	51·6	60·1	−1·8	53·9	60	5·0	5·24	+3·50	17	5·6	43
Perth, W. Australia	1015·2	−1·6	83	43	68·5	50·6	59·5	−1·3	55·9	68	5·0	2·93	+0·71	18	7·4	58
Coolgardie	1014·5	−0·4	91	39	74·7	48·7	61·7	−2·0	52·7	55	3·3	1·02	+0·36	6	—	—
Brisbane	1014·9	−1·3	89	58	79·1	63·6	71·3	+1·5	65·3	71	4·8	11·41	+8·88	14	7·0	55
Hobart, Tasmania	1005·4	−4·9	69	37	59·4	45·3	52·3	−1·8	47·8	66	6·8	3·78	+1·52	23	3·4	26
Wellington, N.Z. ..	1015·1	+1·5	64	40	59·0	49·3	54·1	+1·1	52·2	82	6·5	2·78	−1·30	13	6·3	48
Suva, Fiji	1013·8	+0·6	83	65	79·7	70·6	75·1	−0·7	71·3	82	5·7	8·12	−0·17	21	6·4	51
Apia, Samoa ..	1011·2	+0·2	87	68	85·7	72·7	79·2	−0·3	75·2	83	5·3	9·68	+2·51	20	6·6	53
Kingston, Jamaica	1012·1	+0·6	93	67	88·7	73·6	81·1	+0·6	75·3	78	3·0	3·02	−4·44	8	8·1	69
Grenada, W. Indies																
Toronto	1020·5	+3·0	79	32	62·0	48·2	55·5	+6·9	48·8	86	6·8	1·82	−0·75	9	5·2	47
Winnipeg	1012·7	−2·2	71	7	49·5	33·0	41·3	+0·6	35·3	85	7·2	5·67	+4·30	13	4·0	37
St. John, N.B. ..	1020·9	+5·1	69	29	58·4	43·1	50·7	+5·4	45·2	86	5·4	2·60	−1·94	11	5·9	54
Victoria, B.C. ..	1020·4	+3·3	61	29	54·7	38·5	46·6	−3·7	42·3	91	5·6	2·61	+0·04	11	4·3	39